August 2, 1989

SCHNABEL
ENGINEERING
ASSOCIATES

REPORT
EVALUATION OF SUBSIDENCE POTENTIAL
ABOVE CANE CREEK POTASH MINE
NEAR MOAB, UTAH

Our Ref.   UT 890955

August 2, 1989

August 2, 1989
Our Ref. UT 890955

Moab Salt, Inc.
P.O. Box 1208
Moab, Utah 84532

Attn: Mr. C. Alan Tapp

Gentlemen:

Submitted herewith is our report, "Evaluation of Subsidence Potential Above Cane Creek Potash Mine Near Moab, Utah." This report presents the results of our analyses including predictions concerning the amount of potential surface subsidence expected within the next 100 years.

We have appreciated the opportunity to be of service on this project. Please feel free to contact us if you have any questions.

Sincerely
SCHNABEL ENGINEERING ASSOCIATES, P.C.

Ernest N. Cotton
Senior Staff Geological Engineer

Gordon M. Matheson, Ph.D., P.E.
Senior Associate

EC/sn

enclosure

REPORT
EVALUATION OF SUBSIDENCE POTENTIAL
ABOVE CANE CREEK POTASH MINE
NEAR MOAB, UTAH

INTRODUCTION

This report presents the results of investigations and analyses into the potential for long-term surface subsidence above Moab Salt, Inc.'s Cane Creek Mine near Moab, Utah. The Cane Creek Mine is currently operating as a solution mine that is removing salt minerals left in the abandoned underground mine workings. The abandoned mine workings are at a depth of approximately 2800 to 3300 feet below the existing ground surface. Figure 1 presents the approximate location of the Cane Creek Mine.

INVESTIGATION OBJECTIVES

It is our understanding that the State of Utah has requested the mine operator to provide an evaluation of the potential for subsidence above the Cane Creek Mine that could occur over the next 100 years. The objective of this investigation is to provide the required technical evaluations and develop conclusions on the subsidence potential above the mine. In order to accomplish this objective, the following scope of work has been completed:

o   Review of existing data on the mine including the geology, mining methods, characteristics of the site materials, and convergence data available from previous mining,

o   Review of available data on surface subsidence above potash mines at other sites for comparison to the conditions at the Cane Creek Mine,

o   Analysis and prediction of surface subsidence effects at the Cane Creek Mine based on the data collected, and

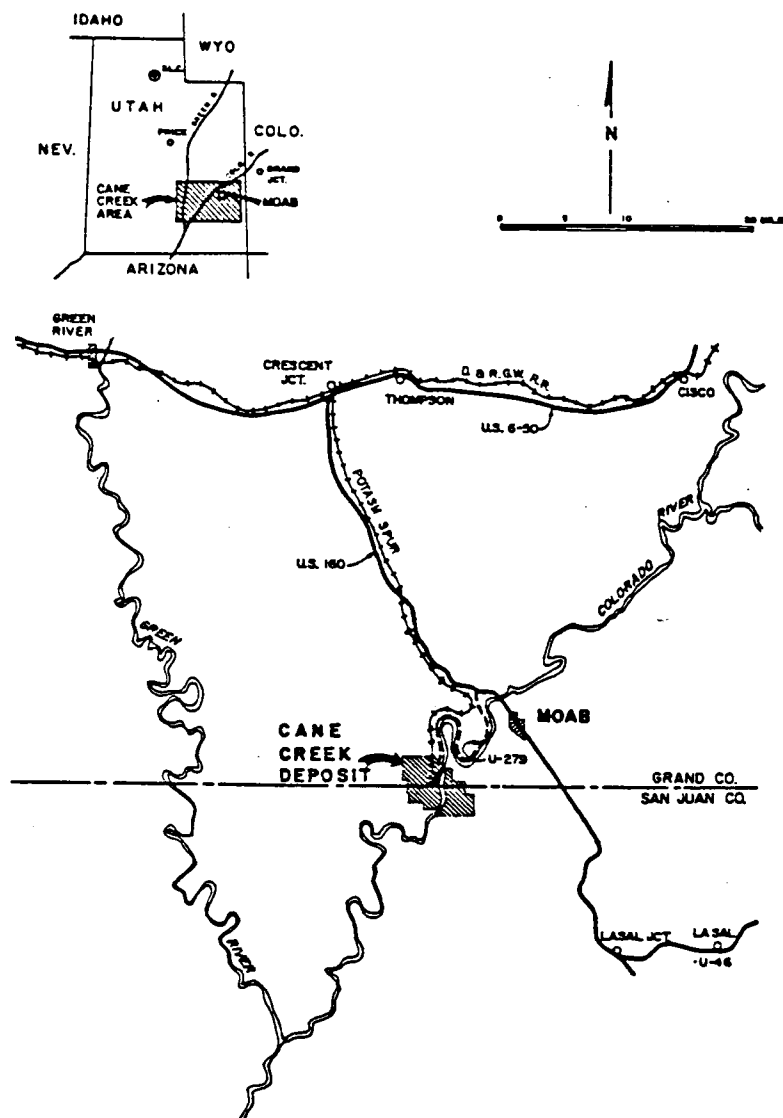o   Preparation of this report summarizing our findings and presenting conclusions.

1

Schnabel Engineering

Figure 1
Location of Cane Creek Mine

It should be noted that no subsurface investigations or laboratory testings were completed for this investigation. Given the site specific data available, it is our opinion that such data collection is unnecessary. The conclusions developed from this investigation, however, are limited by the accuracy and completeness of the available data.

MINING HISTORY AND METHODS

The Cane Creek Mine is located in the Paradox Formation of Permian Age. The mining horizon is in the No. 5 salt bed located between 2800 to 3200 feet below the existing ground surface. Based on geologic data, the mining horizon is overlain by approximately 400-feet of Paradox Formation consisting of interbedded shales, carbonates, and evaporites. Above the Paradox Formation are the Honaker Trail Formation, Lower Elephant Canyon Formation, and Upper Elephant Canyon Formation. The mining horizon is located within the Cane Creek Anticline, a relatively gentle anticline structure in the region. During the development of this anticline, normal and reverse faulting occurred in the sediments overlying the Paradox Formation. In addition, some complicated flow related structures were developed in the evaporate and shale units within the Paradox Formation.

Underground mining at Cane Creek began in the early 1960's. Initially the mining was completed in an irregularly laid out room and pillar operation. Figure 2 presents a map of the mine workings as they existed in about 1969. The areas labeled as 1st West Mains to 1st East Mains were mined first and illustrate the irregular mining pattern. From about 1966 to the end of the underground mining a more regular mining configuration was developed as can been seen on the remaining mine workings on Figure 2.

In general, the mining was carried out by using either a continuous miner, conventional drilling and blasting, or by using a ripper. In all cases, the mined drifts ranged from 8 to 10 feet in height and 18 feet in width. It is our understanding that an 8-foot mine height was used for the majority of the mine. Pillars were left between the openings with crosscuts mined between the drifts for ore extraction and ventilation. The pillars ranged between 50 to 60 feet in
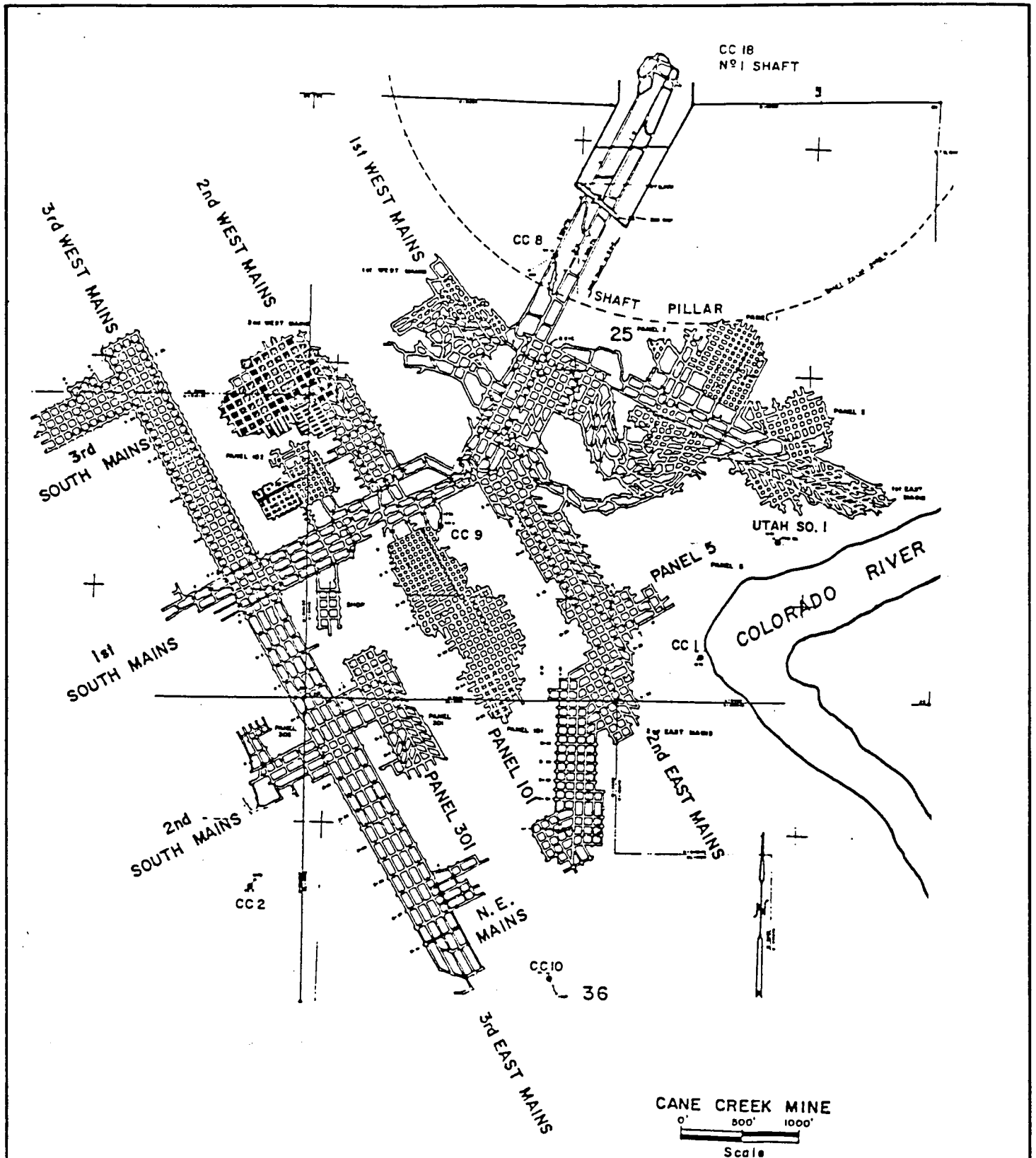
3

Figure 2

Approximate Configuration of the Majority of Cane Creek Mine Workings Showing Typical Mining Layout

width and 50 to 140 feet in length. Larger barrier pillars were left between mining panels to maintain mine stability.

The extraction ratio (i.e., ratio of ore extracted to available ore) varied depending on the mine configuration. In sections similar to 3rd Main East (see Figure 2), the extraction ratio is estimated to be about 32 percent. In areas similar to the 3rd Main West configuration the extraction ratio was estimated to be about 41 percent. In the Panel 101 area, the extraction ratio was estimated to be about 46 percent. Two areas of retreat mining were also indicated on the mine map. These areas are the 2nd West Mains and Panel 102 shown on Figure 2. It is assumed that the extraction ratio in these areas was about 90 percent.

It is our understanding that in 1970 the mine was converted from an underground operation to a solution mine. Available records indicate that solutioning has been achieved by injecting water through well Nos. 4, 5, 8, 12, 13, 14, 15, and 16, and by extracting the solution from well No. 6. The location of these wells is shown on Figure 3. The time periods that each well was used for injection are shown in Figure 4. Based on the injection and extraction locations, it appears that the solution mining is, or has been, extracting ore from most portions of the mine. The zones assumed to be most affected by solutioning is shown on Figure 3. For this analysis, it has been assumed that only the original mined area is, or has been, affected by solutioning. Other ore zones above, below, and greater than 10 lateral feet from the mined zone are assumed not to be affected. Based on extraction records, it appears that an additional 50 percent of the ore in the solution mining zone has been recovered from most areas of the mine, leaving approximately 25 percent of the ore in place.

SALT AND POTASH BEHAVIOR

Salt and Potash, due to their chemical composition, behave as a vicious fluid. Thus, the material will gradually flow with time from areas of higher stress to areas of lower stress. When an underground cavity is opened in such a material, the material immediately begins to creep into the opening. The initial creep rate is high (so called primary creep), however, given time the creep rate generally reduces to a lower, approximately constant rate (so called secondary creep). The
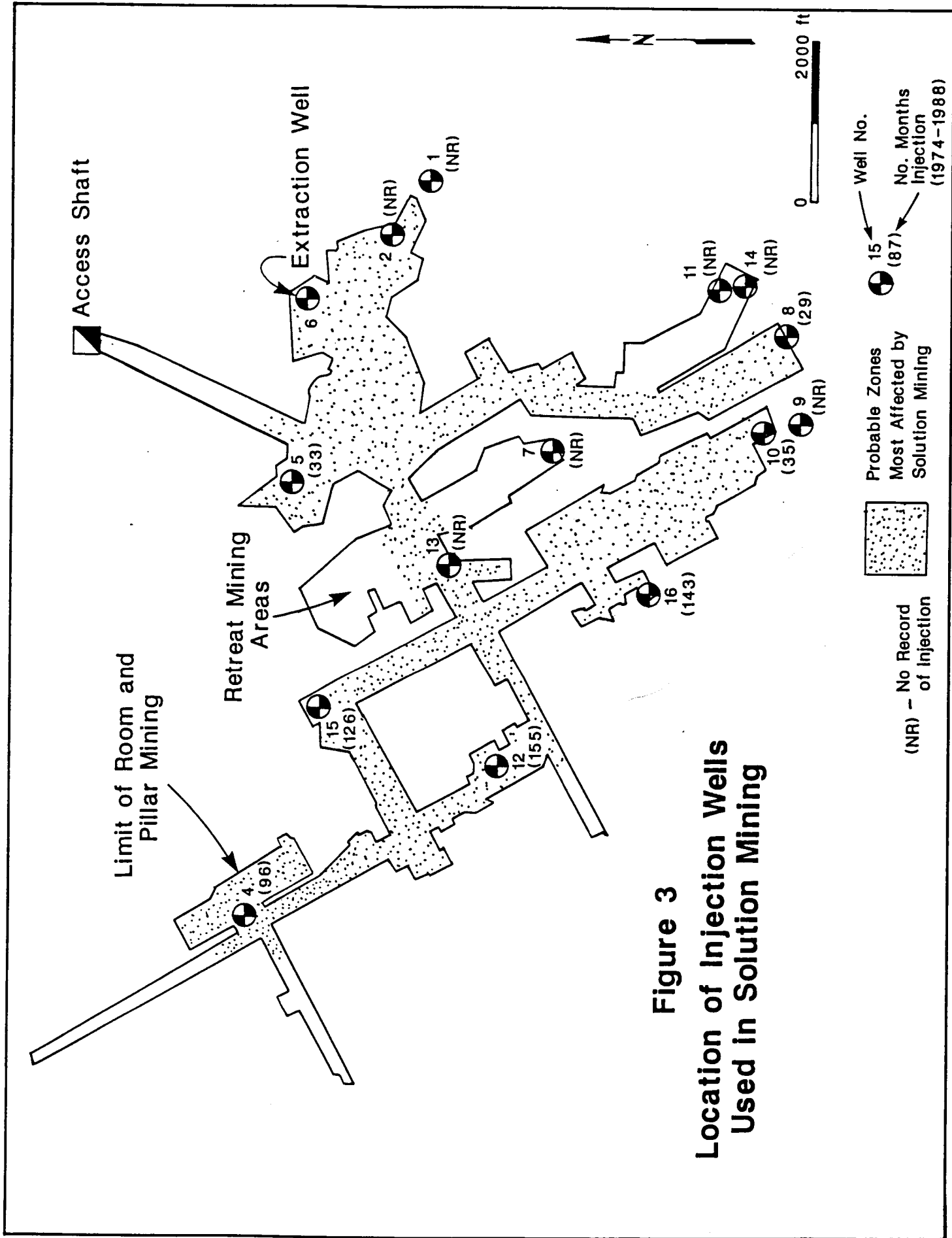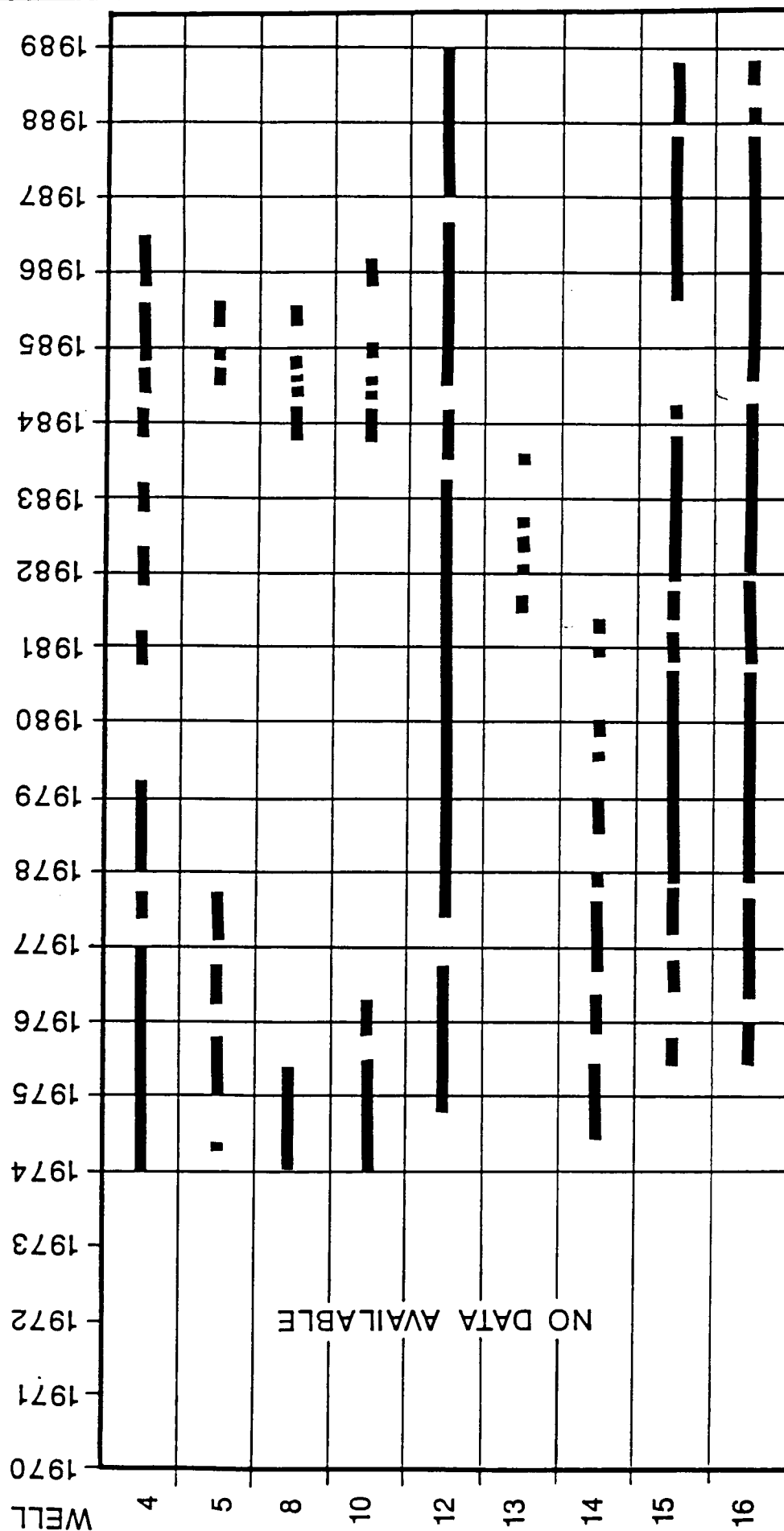
5

Figure 3
Location of Injection Wells
Used in Solution Mining

Figure 4
Well Injection Intervals

rate of creep is a function of the properties of the materials, the stress difference created between the material and the opening, and geometry of the opening. Given sufficient time, the openings will completely close as a result of the material deformations. Failure, rather then creep, can also occur in these materials when the stress difference created by an opening exceeds the quasi-static strength of the rock (so called tertiary creep). This would commonly be expected in retreat mining and solution mining areas. In most other areas, the stress difference is kept sufficiently low to prevent failure and control the closure rate of the openings to allow safe mine operations and equipment access.

Subsidence above salt and potash mines occurs in response to the excavation of the ore and creep or collapse of adjacent ore or other materials into the opening. Review of literature on subsidence above potash mines suggests that the subsidence occurs in much the same form as longwall coal mine subsidence. In the case of longwall coal mining over deep deposits, subsidence normally is manifested as a broad dish shaped trough whose vertical displacement and lateral dimensions are a function of the thickness, length, and width of the coal seam and the characteristics of the overburden materials. For room and pillar potash or salt mining, general configurations similar to that of longwall coal mines can be used for subsidence analysis purposes by assuming an effective mined thickness which is a function of the extraction ratio. In addition, the subsidence above a stable room and pillar areas of a potash or salt mine will gradually occur over a great number of years as compared to longwall coal mining due to the relatively gradual, rather than catastrophic, closure of most openings.

The use of solution mining or retreat mining methods will accelerate subsidence. This results from increased creep rates induced by the high stress difference caused by higher extraction ratios. Higher extraction ratios will also result in greater amounts of total subsidence at the surface. In high extraction areas, collapse of the overburden into the mine opening frequently occurs. This collapse can help reduce the total subsidence caused by the mining due to bulking of the collapsed materials.

8

SITE SPECIFIC SALT PARAMETERS

In order to assess the potential for mine subsidence and the expected time rate of subsidence occurrence, it is necessary to estimate the closure rate of the mine openings. Data is available on the closure rate of the mine opening at the Cane Creek Mine from Wieselmann (1969) and Dryer (1969). This data may be compared to data from other mines to verify that it is of reasonable magnitude.

According to the data available, vertical closure rates for a 10-foot high by 18-foot wide typical mine opening was about 1.8 inches per year at the center line of the drift. Horizontal closure rates were of similar magnitude and reported to be about 1.4 inches per year. Although no mine specific data is available concerning vertical closure at the ribside, rates are typically on the order of 60 percent of that at the room center line for rooms of this size. These closure rates can be assumed to be reasonably representative of the rates for the non-retreated or solution mined areas of the mine.

Creep rates will be substantially higher in retreat mining areas. Mine specific data suggest that a typical creep rate for areas with a 90% extraction ratio should be approximately 24 inches per year. For a 75% extraction ratio the creep rate will be approximately 15 inches per year. The creep rate for these higher extraction areas is probably too high to be sustained as secondary creep and indicates that tertiary creep may be occurring resulting in caving of the roof, floor heave, and failure of the remaining pillars. As a result, subsidence above retreat or solution mining areas probably occurrs concurrently with mining or relatively soon after mining is completed.

The individual room creep rates were compared to creep rates reported for other mines to verify their magnitude. Typical creep rates for deep potash and salt mines openings with similar extraction ratios varies from about 1.6 to 6.7 percent of the opening height at the opening center line per year. Using the previously cited data, the creep rate for the Cane Creek Mine is about 1.5 percent per year. Although this is in the lower end of the previously cited data, it is of the same order of magnitude, therefore, the mine specific rates appear reasonable.

Schnabel Engineering

SUBSIDENCE POTENTIAL

The potential for subsidence above various areas of the mine was evaluated based on a trough subsidence model. For this analysis, a modified version of the method for subsidence prediction outlined by the National Coal Board (1975) was used. The analysis evaluated the maximum estimated potential subsidence above mined areas. For this analysis it was assummed that the mined thickness could be reduced to an effective mined thickness based on the extraction ratio in the mined areas. This effective mined thickness gradually decreases with time due to creep. Figure 5 presents the relation between the extraction ratio and the effective mined thickness for an initial 10-foot and 8-foot mined height.

For analysis of the subsidence potential, the mined area has been broken into a series of broad zones. These zones are schematically shown on Figure 6. Table 1 presents the pertinent assumptions used and results of the subsidence analysis for each of the zones. The results in this table present the total predicted subsidence assuming no subsidence has occurred to date.

Review of Table 1 indicates that the predicted maximum subsidence ranges from 0.60 to 7.6 inches. The zones subject to the maximum subsidence are over the current solution mining areas. The maximum subsidence predicted in Table 1 probably overestimates the remaining subsidence potential above most areas of the mine. Closure of openings has probably resulted from creep. In high extraction areas (i.e. solution of retreat mining areas) the creep rate can be expected to be within the range of 15-24 inches per year. This suggests that complete closure of the predominantly 8-foot high mine openings would occur within 4 to 7 years after mining. Since solution mining in most areas was well underway or completed greater than 4 to 7 years ago, it can be assumed that the majority of subsidence over this area has occurred. It should be noted that the predicted subsidence does not take into account localized collapse of rooms and bulking of collapsed material. This would tend to reduce the total observed subsidence at the surface below the maximum values presented in Table 1.

The maximum predicted subsidence will occur over limited areas directly above the mine and will gradually reduce to negligible values at some distance outside the limits of mining. The remaining subsidence should occur gradually over the next 50 to 100 years and will be very difficult to distinguish on the ground surface. Continued or previous solution mining of other areas of the

Schnabel Engineering
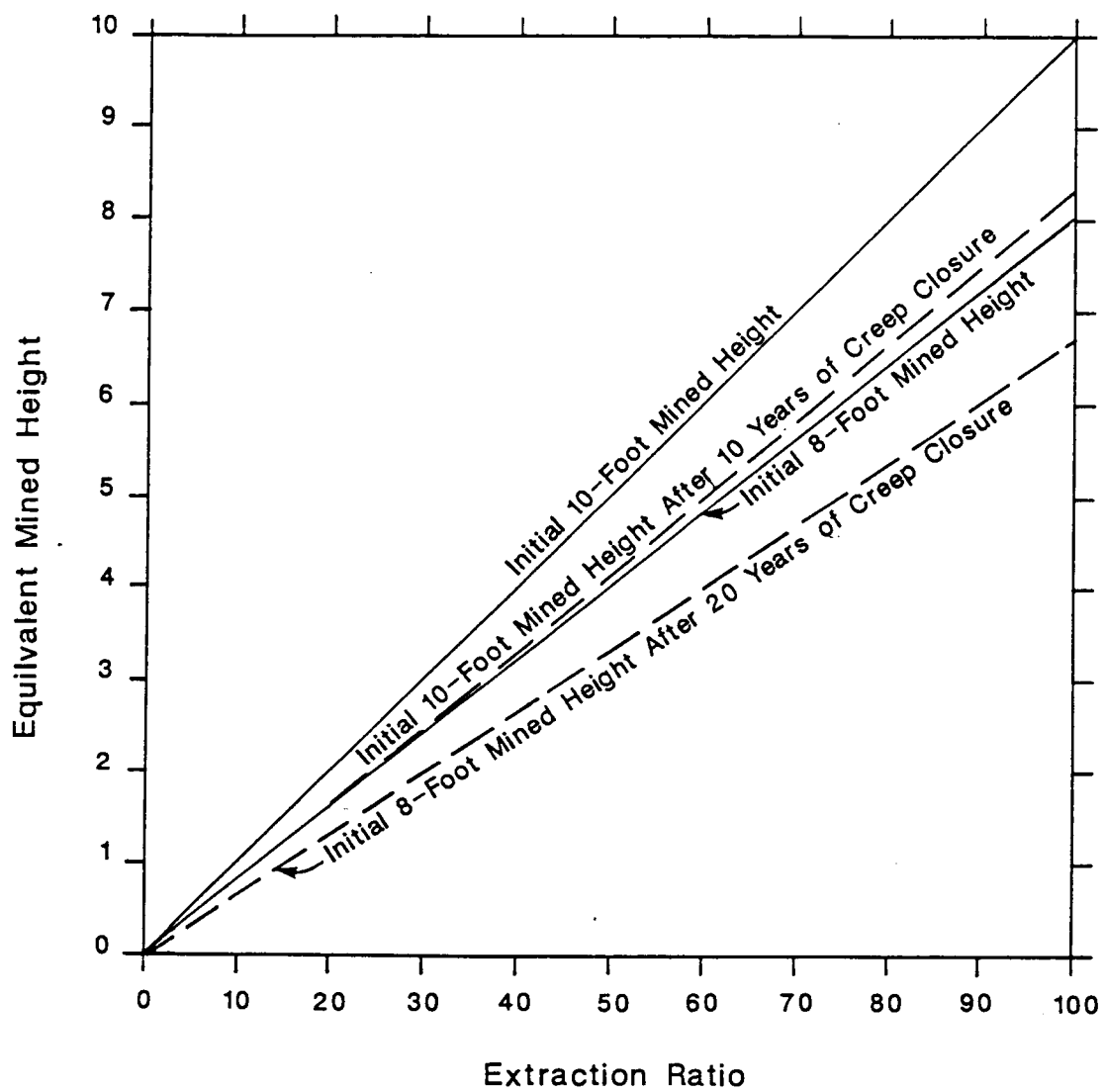
Figure 5

**Relationship Between Extraction Ratio
and Effective Mined Height**

Figure 6
Subsidence Zones

ZONE 1
ZONE 2
+ 3200
ZONE 3
+ 3100
ZONE 4
ZONE 5
+ 3250
ZONE 6
ZONE 8
ZONE 9
ZONE 7
+ 2900
ZONE 10
+ 3200
ZONE 11
ZONE 12
+ 3100
ZONE 13
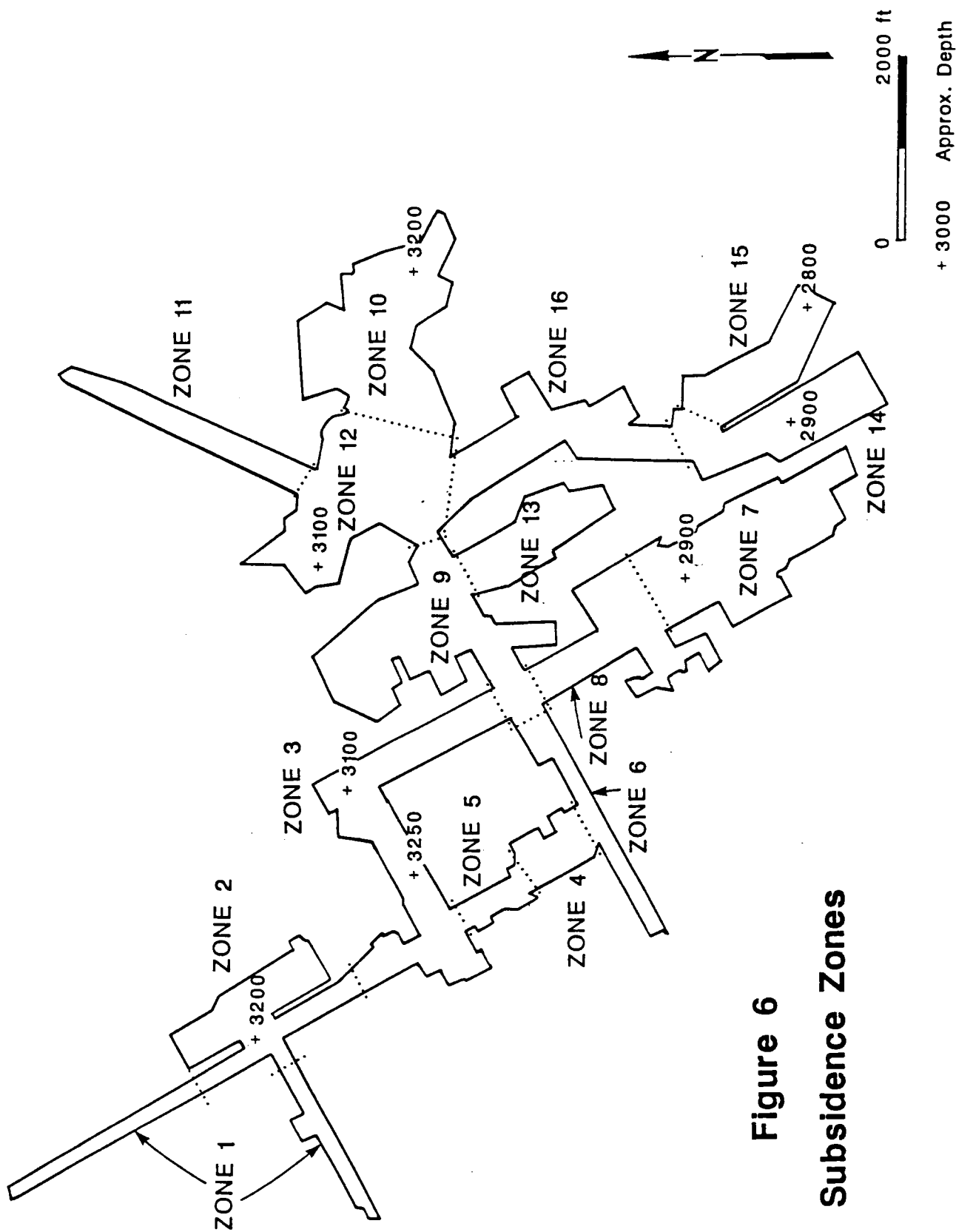ZONE 14
ZONE 15
+ 2800
ZONE 16
+ 2900
N
2000 ft
Approx. Depth
0
+ 3000

TABLE 1

ZONE	DEPTH (FT)	MINED EXTRACTION RATIO (%)	AVERAGE LENGTH (FT)	AVERAGE WIDTH (FT)	NO MONTHS SOLN. MINING IN IMMED. AREA	PREDICTED MAX TOTAL SUBSIDENCE (IN)
1	3000	41	2000	175	0	1.10
2	3200	41	1800	500	96	4.0
3	3200	41	1800	325	126	3.6
4	3250	41	1100	500	155	1.9
5	3250	41	800	300	126-155	0.6
6	3100	32	2200	350	155	3.0
7	3200	32	2600	380	35	4.0
8	2900	32	1500	380	143	2.3
9	3100	90	110	750	0-155	4.2*
10	3200	46	1500	1000	155	6.4
11	3100	15	3000	300	0	2.9
12	3100	41	1500	750	33-155	6.9
13	3100	50	2400	540	0	7.6
14	2900	46	1700	600	29	5.1
15	2800	46	1800	450	0	4.3
16	3100	41	2200	400	29	3.4

* Retreat mining area, subsidence complete

property or other ore zones within the same area will result in an increase in the magnitude of the subsidence potential above these zones. The upper bound of this subsidence, however, should be no greater than the maximum subsidence values presented in Table 1.

CONCLUSIONS

The results of the analyses presented in this report suggest that a relatively minor amount of subsidence can be expected to occur over portions of the Cane Creek Mine over the next 100 years. Specifically the analyses indicate the following:

o   The maximum predicted subsidence above mined areas ranges from 0.6 to 7.6 inches. This subsidence would occur over very limited areas above specific zones and would decrease to negligible values outside mined areas.

o   The maximum predicted subsidence is probably overestimated since it does not account for collapse and bulking of overburden into mined openings.

o   The majority of subsidence should already have taken place over much of the mine since solution mining was initiated greater than 4 to 7 years ago.

Based on the data available it is our opinion that no more that a few inches of subsidence can be expected over the mined area in the next 100 years. It is unlikely that this subsidence will be readily detectable on the surface or have any significant effect on existing surface features.

This report has been prepared in accordance with generally accepted engineering practice. No other warranty, either expressed or implied, is made.

14

Schnabel Engineering

REFERENCES

Dreyer, W. (1969). Planning and Commissioning of the North American T.G.S. "Cane Creek" Potash Mine in the state of Utah (in German). Bergb. - Wiss, 16, p.p. 441-446.

National Coal Board (1975). Subsidence engineers handbook, Mining Department, London, England.

Wieselmann, E.A. (1968). Closure measurements an important tool in mine design at the Cane Creek Potash Mine. Tenth Symposium on Rock Mechanics, Austin Texas, 1968.

Schnabel Engineering

This page is a reference page used to track documents internally for the Division of Oil, Gas and Mining

Mine Permit Number _M019005_   Mine Name _Cane Creek Potash_
Operator _Moab Salt LLC_   Date _Augus 2 1989_
TO _____ FROM_____

__CONFIDENTIAL   __BOND CLOSURE   __LARGE MAPS   _X_EXPANDABLE
__MULTIPUL DOCUMENT TRACKING SHEET   __NEW APPROVED NOI
__AMENDMENT   _OTHER_____

Description   YEAR-Record Number

__NOI   _X_Incoming   __Outgoing   __Internal   __Superceded

Evaluation of Subsidence Potential
_____
_____

__NOI   __Incoming   __Outgoing   __Internal   __Superceded

_____
_____
_____

__NOI   __Incoming   __Outgoing   __Internal   __Superceded

_____
_____
_____

__NOI   __Incoming   __Outgoing   __Internal   __Superceded

_____
_____
_____

__TEXT/ 81/2 X 11 MAP PAGES   __11 X 17 MAPS   __LARGE MAP

COMMENTS: _____
_____
_____

CC: _____